DESIGN AND CFD APPLICATIONS OF GAS TURBINE COMBUSTION CHAMBER

K.L Narayana[1]
[1]Assistant professor, Department of Mechanical Engineering, ABR College of Engineering and Technology, Chinairlapadu Village, Kanigiri, Andhra Pradesh- 523254
K. Bhupathi Srinivas [2], **K Sivaraj Kumar** [3], **Arekanti Raju** [4], **S. Ramprasad** [5], **P. Surya Kishore** [6]
[2,3,4,5,6] Students, Department of Mechanical Engineering, ABR College of Engineering and Technology, Chinairlapadu Village, Kanigiri, Andhra Pradesh- 523254

Abstract:

The combustion chamber is an integral feature of the Brayton cycle. The fuel and air mixture are burned in a combustion chamber to produce heat and electricity. This power is transferred to the bucket, which in turn drives the turbine. Gas generator speed and performance, as well as fuel-air mixture parameters during combustion, need to be studied soon. There are factors to be taken into account in the project that determine the basic geometry of the "standard" gas turbine blender. It's also instructive because it details the essential parts of a combustion chamber and how they work together to produce heat and light. As it came time to move forward with the project after conducting several testing's, CFD modeling was continued. The dynamics of the fuel-air combustion mixture were monitored using ANSYS software. The ratio of fuel to air in the swirl effect wasn't the only factor in determining efficiency, though. The combustion chamber included a liner wall with holes perforated all around the body to facilitate recirculation (swirl). The efficiency of the combustion process is also impacted by this. Using simulation, the flow pattern was able to be detected. The simulation result can be used in the chamber's design and in other efforts to boost the efficiency of the combustion process.

Keywords: combustion chamber, Thermal coating, CFD

1.0 INTRODUCTION

The chamber's difficult job is to burn fuel, with fuel spray pockets, with air from compressor, and with heat released to expand and speed up the air, all while maintaining a uniformly heated gas stream for the turbine. This objective must be accomplished with the least amount of pressure loss and the most amount of thermal release possible in the allotted area. A key variable is the amount of fuel released into the air to achieve the desired temperature rise. However, the upper limit is only between 850 to 1700 degrees Celsius. What makes up the blades and buckets of turbines. A temperature of 200 to 550 degrees Fahrenheit was achieved in the heated air. C. Combustion results in a temperature range of 650-1150 degrees Celsius, which is increased during the compression process.

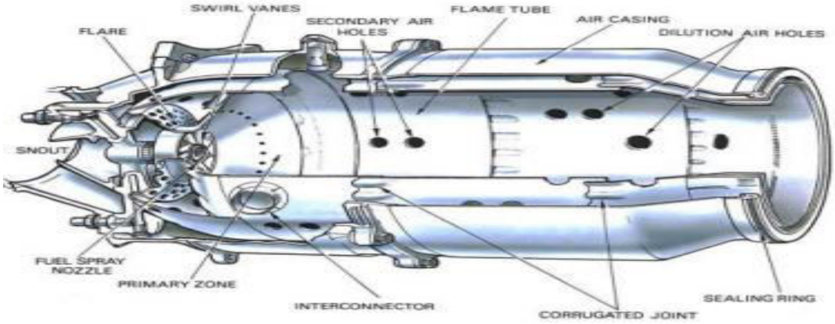


Figure 1: Combustion

The turbo propeller motor needs to have a consistent and efficient combustion chamber under a wide range of thrust conditions, as the gas temperature required at the turbine fluctuates with motor thrust. Public's perception of air pollution as exhaust smoke increased with the dramatic expansion in commercial air travel, prompting engineers to develop ever-more-efficient combustion technologies. An electric spark initiates combustion in a gas turbine's typical open cycle. Still, once the flames get going, they must be able to sustain themselves without any further input from the spark plug.

Combustion chamber performance:

Important considerations are the efficiency of combustion chamber

- The lack of pressure,
- Efficiency of combustion,
- Toward distribution of outlet temperature;
- limitations of stability and
- Towards the intensity of Combustion.

Thermal Barrier Coatings:

The TBC is a ceramic material that can be sprayed on the interior of the combustion liner. Since, TBC materials are typically low in emissivity and thermal conductivity, they reflect a sizable portion of incident radiation and act as a thermal insulator between the line and hot combustion gases. Typically, a TBC has a metal bottom layer and one or two ceramic layers on top. The liner can be protected from oxidation and corrosion by using a coating resistant to oxidation. A 40-70 K temperature reduction is possible with a sheet thickness between 0.4 and 0.5 mm.

Limitations

The geometry design was performed on a desktop. The grid development process had to be reduced due to the limited project time and thus the combustor geometry had to be simplified

The area within the cylinder where the air/fuel mix is ignited is a combustion chamber. The piston compresses the mix of the air/fuel and holds the spark plug, which combusts and pushes the mixture out in the form of energy from the combustion chamber.

Scope of the work:

Gas turbine engine use internal combustion system to generate thrust. It is all depend on the burning of fuel to produce power. The original substance is called the fuel, and the source of oxygen is called the oxidizer. The fuel can be a solid, liquid, or gas, although for airplane propulsion the fuel is usually a liquid. A primary objective of combustor design is to achieve satisfactory mixing within the liner and a stable flow pattern throughout the entire combustor, with no parasitic losses and with minimal length and pressure loss These requirements necessitate more emphasis on Computational Fluid Dynamics (CFD) simulation of the combustion flow field to reduce testing and improve performance which is a complex problem. The flow field conditions at the combustor exit in real gas turbine engines are highly non-uniform in temperature, pressure, and velocity. These non-uniformities are a function of the combustion chamber flow

Problem of the statement:

The gas temperature required at the turbine varies with engine thrust, and in the case of the turbo-propeller engine upon the power required, the combustion chamber must also be capable of maintaining stable and efficient combustion over a wide range of engine operating conditions. Efficient combustion has become increasingly important because of the rapid rise in commercial aircraft traffic and the consequent increase in atmospheric pollution, which is seen by the general public as exhaust smoke. The sudden rise in temperature observed near the tip of the injector indicates the generation of shocks which help in superior air-fuel mixing. Superior air-fuel mixing resulting in better quality of combustion and thus better performance.

Objectives:

- To determine the efficiency of the gas turbine combustion chamber.
- To study the flow of fuel-air mixture in the gas turbine combustion chamber by experiment and CFD analysis.

2.0 LITERATURE REVIEW

Arthur H. Lefebvre **[1]** The liner comes with cooling slots so it is regularly regenerated by a different film since the cooling capacity is exhausted. The main function of those slots is to act as a relatively cool buffer between the weak liner and reactive gases. If cooling slots are not planned, thermal damage could be caused to the liner. Uma maheshwar Praveen **[2]** The combustor has been constructed according to the combustor sizing concept to take into account all the operating points, i.e. idle, full strength, and the smallest combustor geometry to ensure reliability across the entire range of activities has been obtained. D. S. Crocker, D. Nickolaus **[3]** In order to analyse the effusion cooler output in real-life combustion chamber with heavy rotation und primary troughs, wall temperature and refreshing efficiency of DE flexible holes were analysed. Better than traditional methods, effusion cooling efficiency was found. Harsh. A,Tsukasaki **[4]** Nano liquids in base liquid are metal or non-metallic suppression (1-100 nm) and are incorporated to provide impressive tilting over ordinary exchange of warmth liquids. Warm exchange qualities can be expanded by improving the thermo physical properties of nano fluid. Xiao LIU and Hongtao **[5]** in their study represents most recent progressions in investigation of Nano liquids, and in addition arrangement techniques, working for warm exchange enhancements, and use in heat exchange field. Choi, U. S., **[6]** The Nano liquids are orchestrated by either single step is two stages. In single step the vanished metal is made consolidate with a thin film of construct liquid set in light of turning ring. to each other and small-scale reactor can be put in high temp water shower if warm is expected to achieve the response. Pak B.C., Cho Y.I., **[7]** In their study to diesel engine under turbulent stream condition of micro liquid with size of nanoparticles of 20 nm and volume based up 2 percent is numerically researched. Wind power and Nano liquid cold have established temperature exchange connections to determine close convective and general coefficients of warmth exchange and also to draw power from nano-liquid streaming in the radiator at a certain warmth trade limit. Charyulu, et al **[8]** The diesel motor innovation has been driven by progressively stringent laws. To consent to these laws the discharges control frameworks are quickly creating in the market went for giving items that meet future emanations guidelines, however investment funds in fuel utilization and more noteworthy sturdiness and intensity in worldwide markets, enhancing money saving advantage proportion Lee, S. Choi,S **[9]** A transient hot-wire technique was applied to Oxide Nano fluids and their warm high conductivity were measured. The test shows that these Nano fluids have generously higher warm conductivities with a limited number of nanoparticles than related fluids without nanoparticles.

3.0 METHODS AND MATERIALS

The combustion chamber is where two natural disasters take place; at the fuel inlet, the air is mixed in its entirety or to an appropriate extent. However, air and fuel should be combined before burning in certain combustibles with air before burning. to achieve a smooth burning. This part of the gas turbine is critical for several reasons. In a badly built combustion chamber we will tackle issues, to keep it simple.

There are several problems that can occur:

- Poor mixture: If fuel is not sufficiently combined with air, it may burn incompletely, leading to a higher CO, soot, NOx and hydrocarbons (UHC).
- Differential combustion: This occurs when a section temperature is high but cooler in the surrounding sections, which can cause additional thermal stress. Heat stress can cause fatigue and failure of materials in time.

The Parallel lines methodology aims to provide, according to input details, the key sizes of a gas chamber tubular combustion turbine. The reference parameters, based on the mass flow, the temperature and the reference area used, are initially determined. These quantities are used to evaluate and compare the flow characteristics with other combustion chamber schemes, such as speed, Mach number and dynamic pressure.

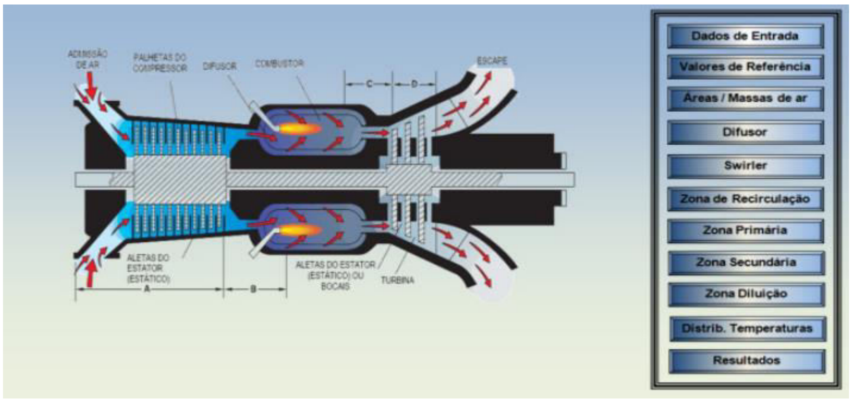


Figure 2: Initial screenshot of the Excel spreadsheet developed

Material properties:

SS316: Alloy 316 is austenitic austenitic molybdenum-bearing stainless steel. The higher content of nickel and molybdenum in this class permits better overall corrosion-resistant properties than 304, in particular with regards to chloride pitting and cravings corrosion.

	C	Mn	P	S	Si	Cr	Ni	Mo	Ti
SX316 SX316L SX316Ti	0.08 max 0.03 max 0.08 max	2.0 max	0.045 max	0.030 max	1.0 max	16.0 to 18.0	10.0 to 14.0	2.00 to 3.00	0.5 max 5X%C

Hot working:

Temperature finish: above 900oC for upsetting operations, forging Should be concluded between 930oC and 980oC All hot operations should be accompanied by upset.

Cast iron:

The main difference in output between forged and cast iron is that cast iron is not handled using hammers and instruments. There is also a compositional variation cast iron contains 2–4% carbon and other alloys and 1–3% silicon, enhancing the casting strength of the moulded metal.

Type of Iron	Carbon	Silicon	Manganese	Sulfur	Phosphorus
Gray	2.5 - 4.0	1.0 - 3.0	0.2 - 1.0	0.02 - 0.25	0.02 - 1.0

COMBUSTION PROCESS:

At speed of up to 500 feet per second, but since the air velocity from the engine compressor is much too high for combustion, the first thing the chambers need to do is discharge it, i.e. decelerate it and increase its static pressure. Since the speed of burning kerosene is just few feet per second at usual mixture ratios, any lit fuel even on the airflow that now has a speed of approximately 80 feet per second will be blown off. Thus, a region of low axial velocity must be formed in the chamber, so the flame will remain in a light in the combustion chamber from 45:1 to 130:1, But kerosene only burns efficiently at or near a ratio of 15:1 and therefore fuel must be burned in a chamber called primary combustion zone with only part of the air entering it. It can be done through a flame tube (burning liner) which has different devices to calculate the airflow distribution in the chamber. Around 20 percent of the air mass flow through the snout or entrance segment Swirls and a perforated flare are immediately downstream, through which the air moves through the primary combustion region. The swirling air causes a flow to the middle of the burning tube upstream and facilitates the desired recycle. The non-acquired air flows into the ring space between the flame tube and the air enclosure

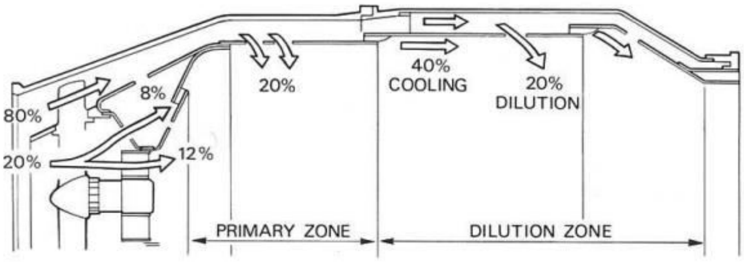


Figure 3: Airflow distribution along the chamber

A number of secondary holes are selected through the wall of the flame tube, adjacent to the combustion zone, which allow an additional 20% of the main airflow to reach the primary region.

DESIGN OF COMBUSTION CHAMBER

The tetra-hedron unstructured grid has been generated using GAMBIT the Fig. shows the 3-D grid model of tubular combustion chamber with 148808 nodes and 781989 elements selected for CFD simulation.

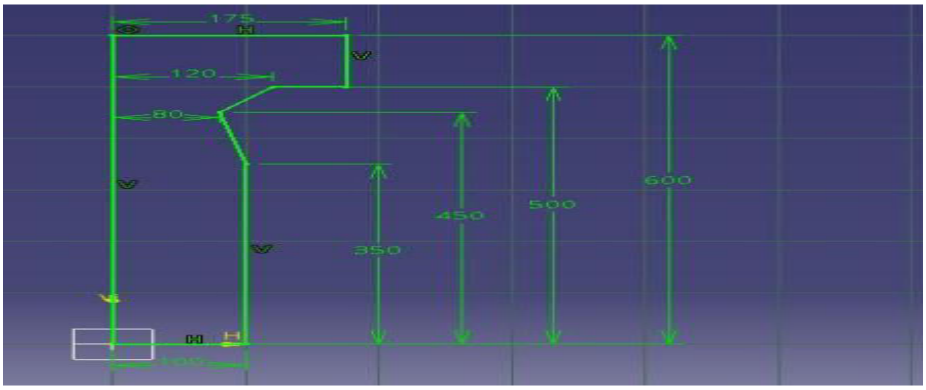


Figure 4: Geometric view

Model: two-step model. Combustion-turbulence interaction model: Eddy dissipation.

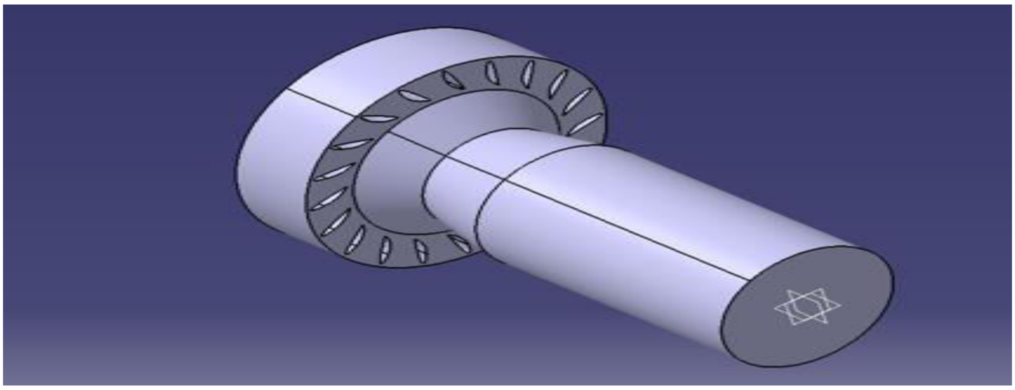


Figure 5: gas turbine combustion chamber

Combustor mesh and boundary condition:

The tetra-hedron unstructured grid has been generated using GAMBIT 2.2. The fig. Displays the tubular combustion chamber 3-D grid model with 148808 nodes and 781989 selected elements in the CFD simulation. The combustion inlet has been defined as a total pressure and the total temperature and at the combustion core exit the static pressure along with the target mass flow rate was specified.

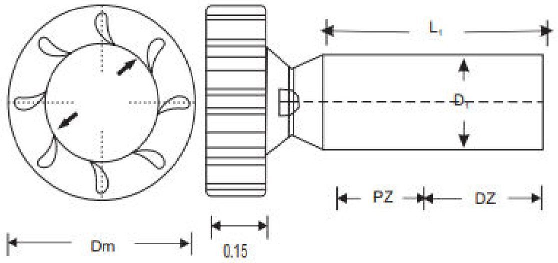


Figure 6: Cross sectional view of combustor

The combustion inlet has been defined as a total pressure and the total temperature and at the combustion core exit the static pressure along with the target mass flow rate was specified. As initial conditions for the inlet turbulence, turbulent strength and hydraulic diameter are indicated.

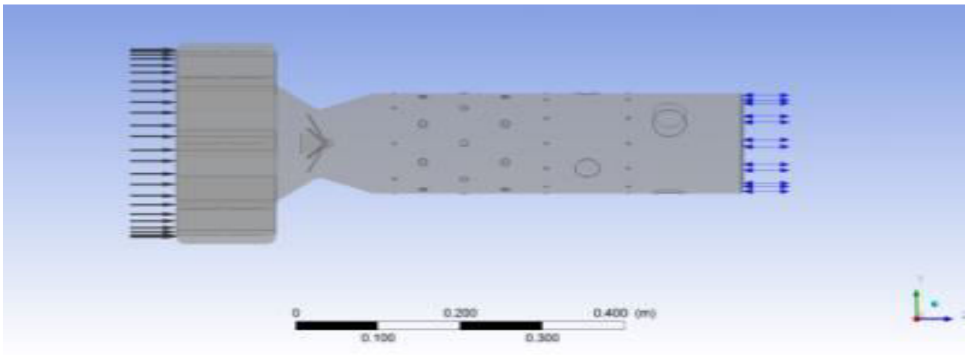


Figure 7: Governing equations

Table 1: Computational mode

Fluid model	Thermal enegry
Turbulence model	k-ε
Combustion model	Laminar flamelet with PDF
Radiation model	Discrete transfer
Combustion reaction	Flamelet library
Nitrogen	Constraint

Flow solution ANSYS CFX v13.0 is used as solver. The numerical settings for the solver are described below

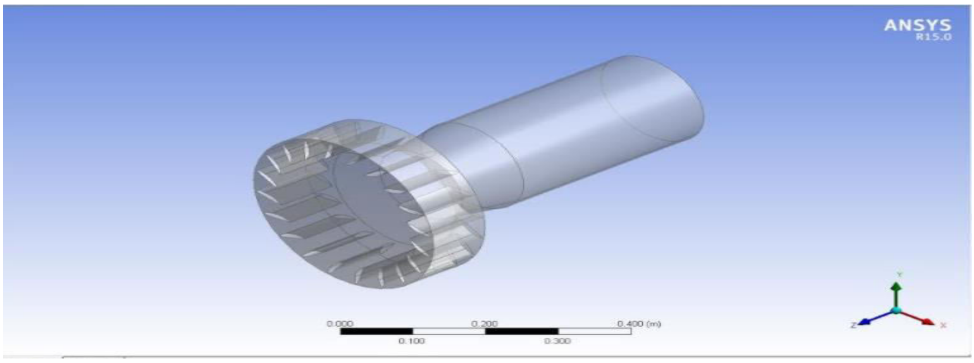


Figure 8: Importing of combustion chamber to ANSYS and inlet

RESULTS AND DISCUSSIONS

We use the thin wall interface, a new feature in ANSYS CFX 15, to model conduction and convection. Software restriction means that this interface is not restricted but should be within the computational domain. We must therefore add another area to the former domain, as is seen in figure

All borders with atmospheric pressure are opening up for this additional domain. The research was conducted in two cases on two separate geometric models. The purpose of this analysis is to evaluate the best model by taking into account the performance results. The two distinct turbulence models, the k-β model and the K-to SST model, were also used in this analysis. The temperature, the strain, the axial speed and the main species CH4, CO2 and CO were all compared.

STAIN LESS STEEL 316:

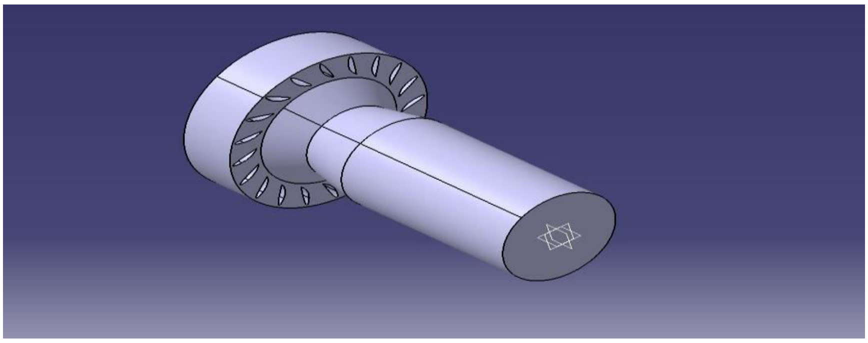


Figure 9: Isometric Model

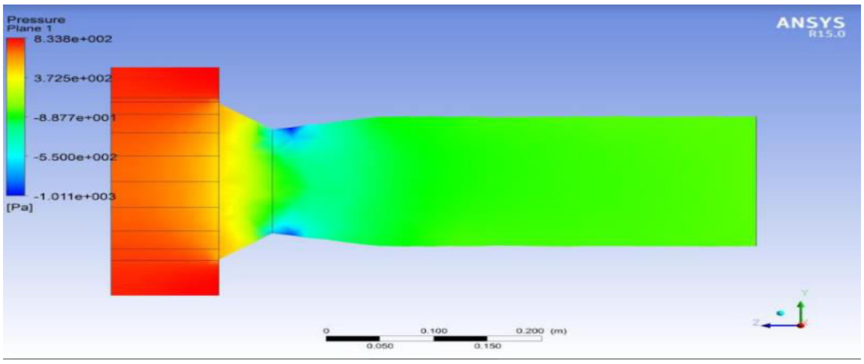


Figure 10: Pressure plane1

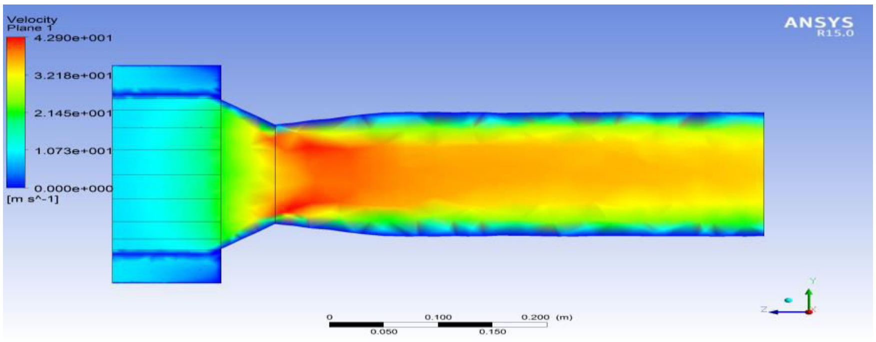


Figure 11: Velocity plane

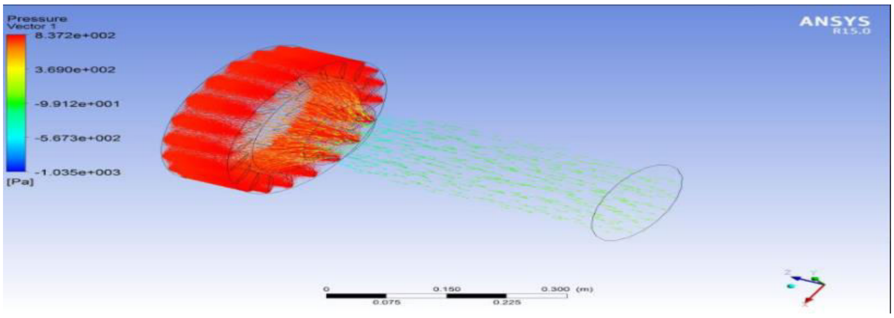


Figure 12: Pressure vector 1

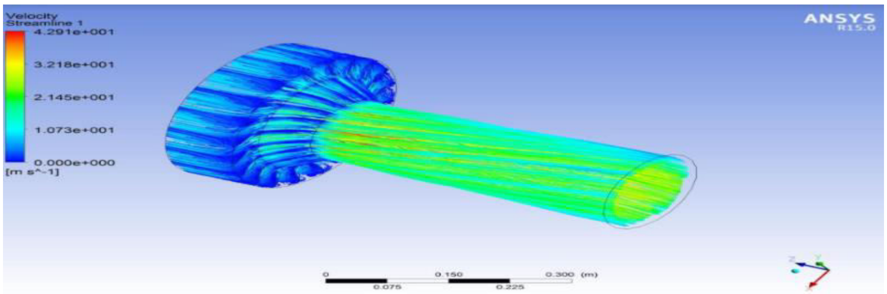


Figure 13: Velocity streamline 1

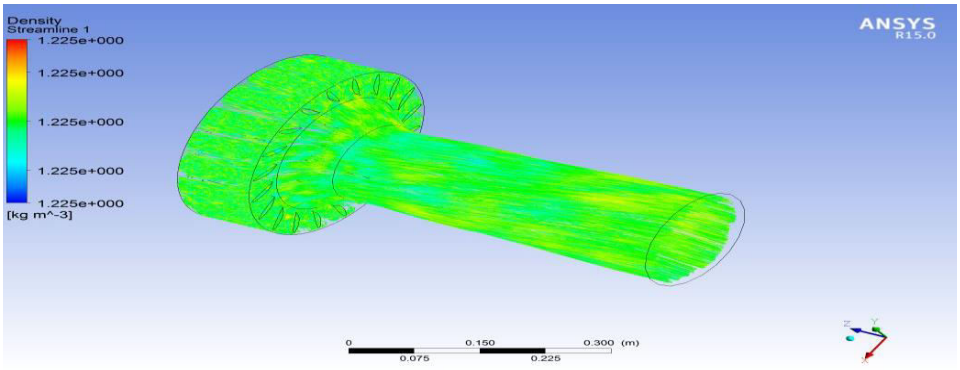
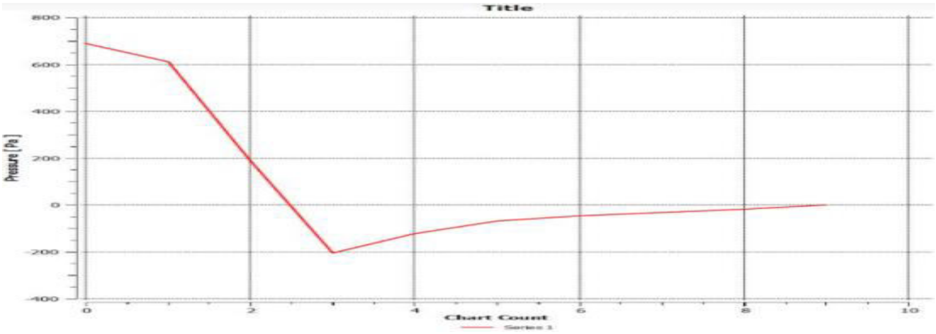
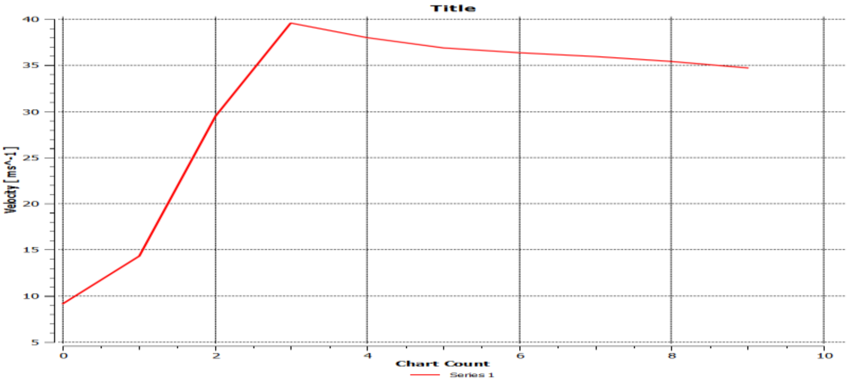


Figure 14: Density stream line



Graph 1: Pressure profile case1 model



Graph 2: velocity profile case1 model

Case 2

This case is another model study that implies that we will evaluate various fluid properties in the model but all have the same solution environment.

Configuration are:

Model of turbulence: k- for SST,

Automatic, wall function:

Absolute energy with viscous term of job,

Model for combustion: Eddy Dissipation and Finite Rate
Boundary conditions, except the model, are always the same.

Cast iron material analysis:

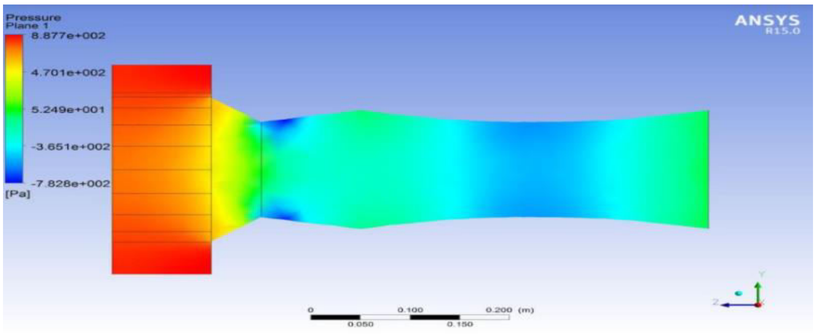


Figure 15: Pressure plane 1

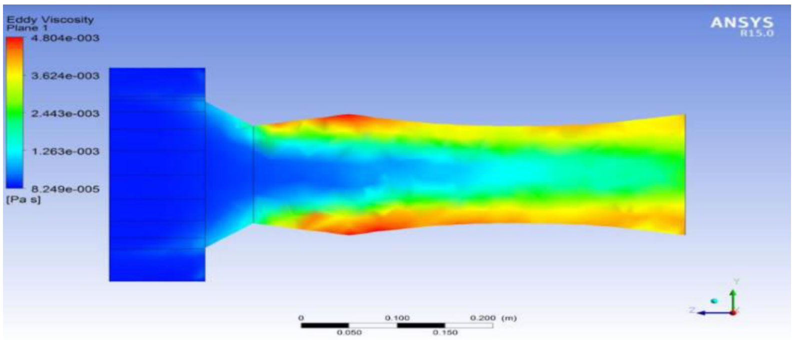


Figure 16: Eddy viscosity plane 1

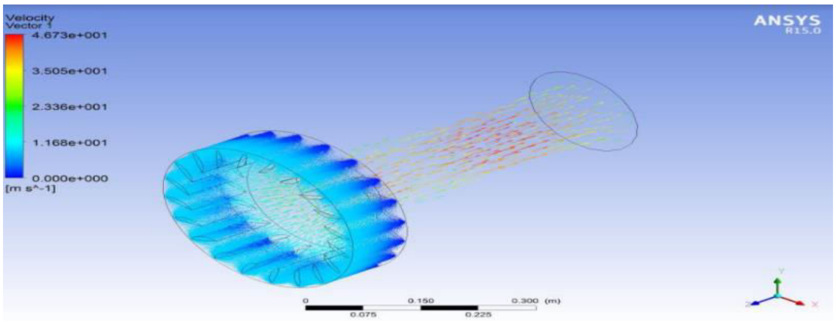


Figure 17: velocity vector 1

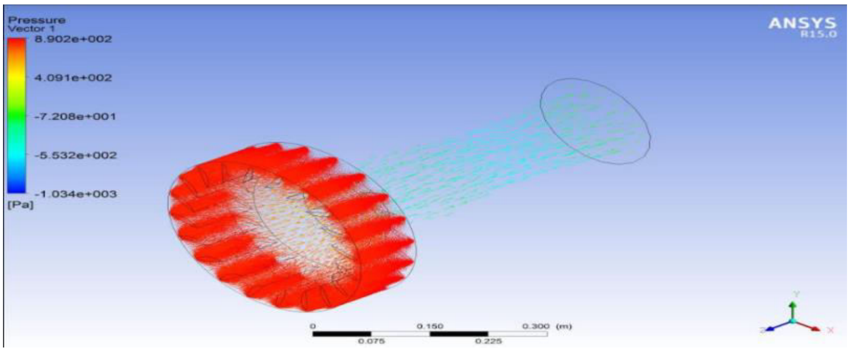


Figure 18: pressure vector 1

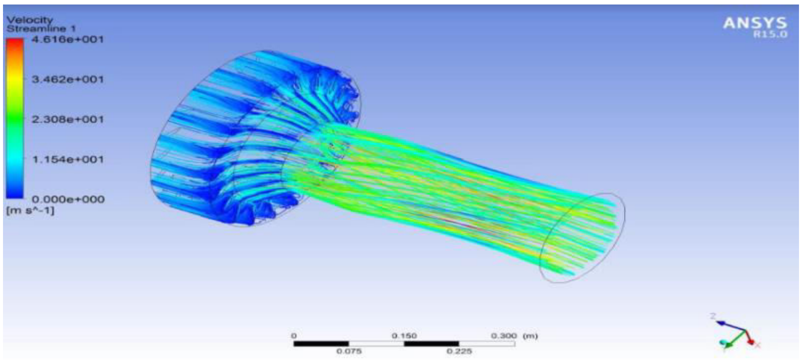
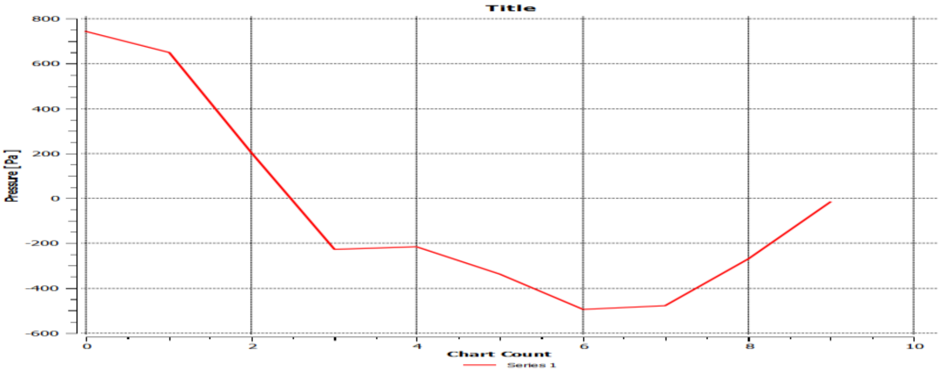


Figure 19: velocity steam line 1

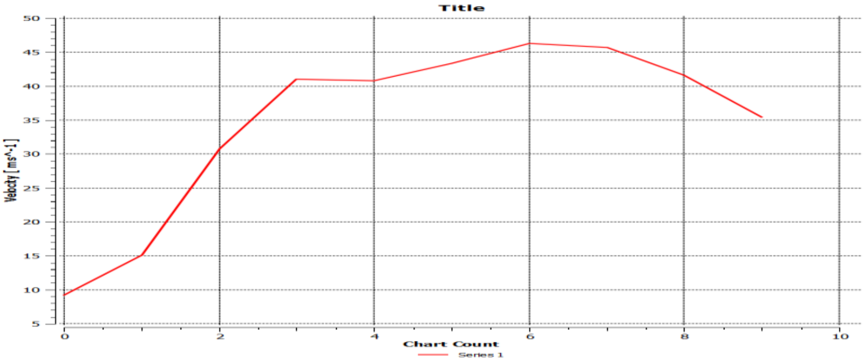
Profile study

In this section we will study area average values of properties on YZ, YZ, YZ and YZ.



Graph 3: Pressure profile at different YZ planes

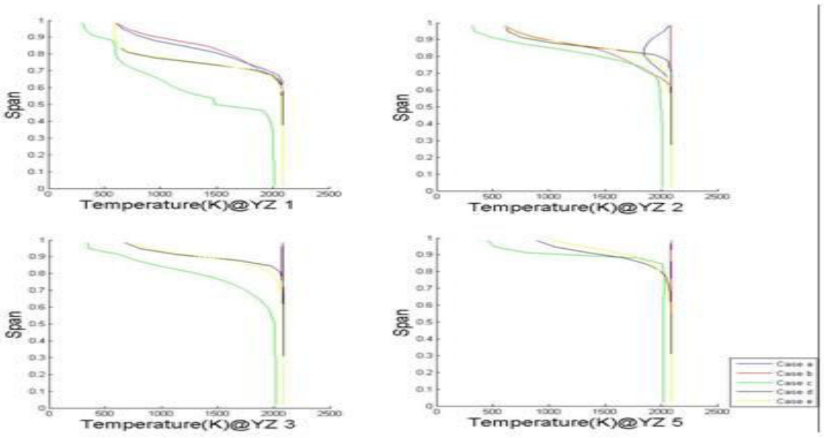
These profiles show that all cases have the same pressure distribution, but at the YZ profile one can observe a jump that presents rather than a physical reality a numerical error in solution.



Graph 4: Velocity

Profile study

Data are presented as a curve vs. span in this section. The range of span is between 0 and 1. 0 refers to the point in the centre line and 1 refers to the outer walls of the point. The figures shown in the diagram are the ring mean. It must be remembered that the time for case c covers a further area.

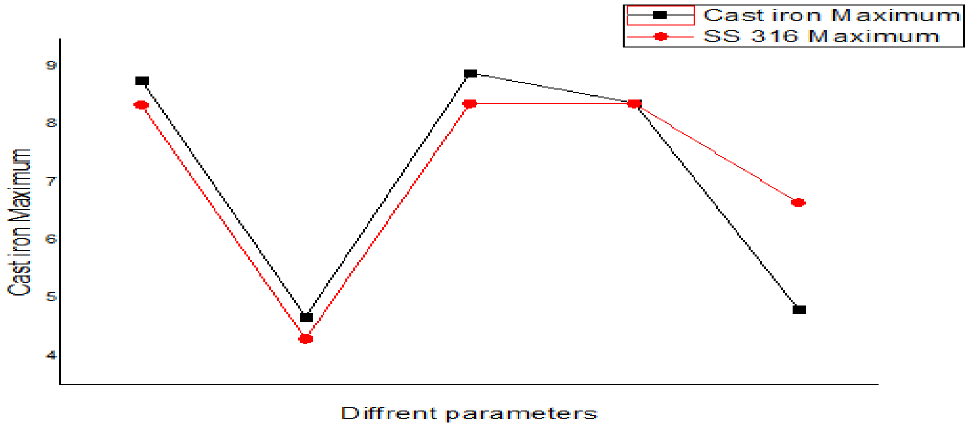


Graph 5: Temperature profile

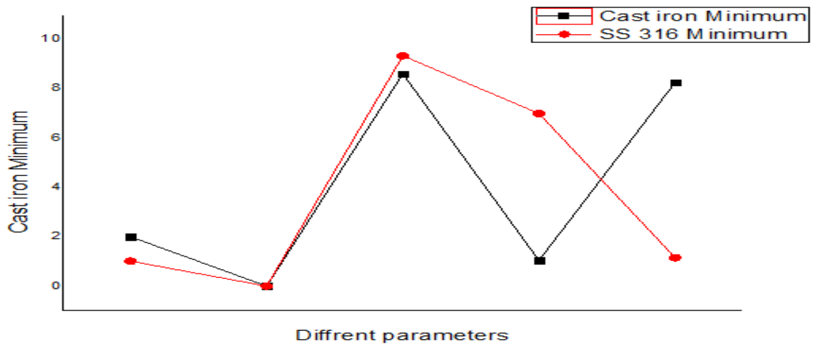
Case c and case e are likely to be lower due to thermo transfer, as shown in the Figure in the Case c and e at the start of the camera, YZ 1 is highly influenced by ambient temperature as the final temperature of 2000K can be seen just 40% of the time. The flux will be heated as it passes forward. In YZ 5 in Figure the final temperature hits approximately 90% or 41% of its movement is moved after the flow.

Table 2: comparison of Gas turbine combustion chamber different materials minimum and maximum deformations

	Cast iron		Stain Less Steel 316	
Parameters	Maximum	Minimum	Maximum	Minimum
Pressure plane	8.77e+002	002	8.338e+002	1.011e+003
Velocity plane	4.673e+001	0	4.290+001	0
Pressure streamline	8.891e+002	8.599e+002	8.363+002	9.330e+002
Pressure Contour	8.372	1.035	8.362e+002	6.990e+002
Eddy viscosity plane	4.804e-003	8.249e-005	6.649e-003	1.15e-004



Graph 5: Gas turbine combustion chamber different materials Maximum deformations



Graph 6: Gas turbine combustion chamber different materials minimum deformations

Discussion

Various turbulence models have been checked in the section the above plots Each template has been tested with the same inputs and results have been demonstrated to be models independent, and these models have the same simulation of the flow area. One can expect one model to work better for pressure scenarios. The second model structure in the section is the same for all cases and it was easier for temperature cases, but different settings have been used and results are compared. Both materials prefer to evaluate the graphs, and eventually conclude that the above SS316 results are more than the cast iron material. Different models provide various field flow models as expected. By triggering the flame's heat transfer pattern, it will alter. Heat transfer plays an important role in chamber functionality. As shown in cases c, d and e, the inflame may cause damage to the blade and unbranded carbohydrates if the outlet of the system is reached. Only after experimental validation can you select the best one.

Conclusion:

The pressure plots and pressure profile of cases should be referred to; pressure distribution may differ depending on the number of iterations, and the charts and plots can also vary. The pressure shift falls within an acceptable numerical error range; thus, the findings have been acceptable. The conclusion of the model-study is that it is appropriate for the 500K scenario, or that the outcome is grid-independent. These results are based on continuous state simulations and have not been evaluated on temporary simulations due to time limits in the project. The suggestion is to use the k-sum SST model with heat transfer for the continuous state simulations, taking into consideration all three situations. This model has demonstrated a successful convergence and also predicts a better flow field than the other cases.

Future works:

More models should be tested for future work. In addition, CH_4 is used as a fuel for the simulations made in this work and varieties of fuels are available. Proposal for future work:

- Test various fuels
- Modeling the combustion generic gas turbine with the various fuel and air inlets and pre-heated air use.
- Temporary simulation grid analysis

Although preliminary tests were conducted on each sub module as discussed in the main body of the thesis, comparison should be made between relevant combustor geometry and operating conditions for further validation. Integration of the three sub modules would also be a future objective following this validation. The combustion modeling can also be improved through implementation of evaporation models and detailed network configurations that allow for emission prediction and flame stability

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